PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01R 31/36 | A1

(11) International Publication Number: WO 97/15839

(43) International Publication Date: 1 May 1997 (01.05.97)

(21) International Application Number: PCT/US96/16797

(22) International Filing Date: 21 October 1996 (21.10.96)

(30) Priority Data:
08/549,432 27 October 1995 (27.10.95) US

(71) Applicant: GLOBE-UNION, INC. [US/US]; 5757 North Green Bay Avenue, Milwaukee, WI 53209 (US).

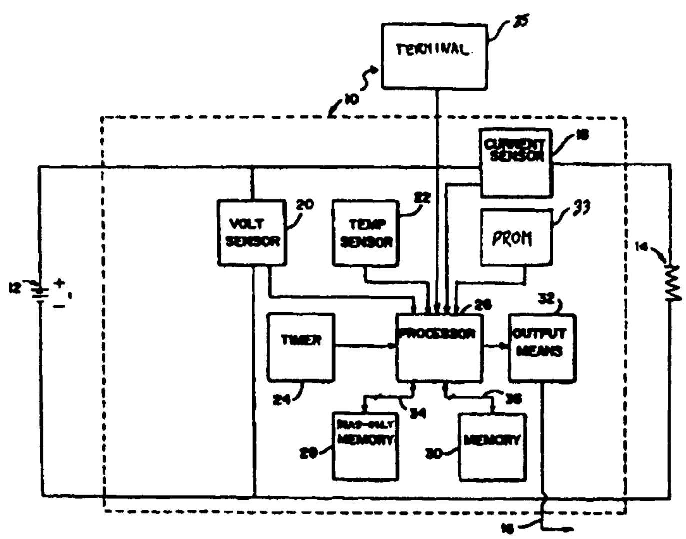
(72) Inventor: ROSS, William, J.; 354 Atkinson Street, Mukwonago, WI 53149 (US).

(74) Agents: SITKO, Anthony, G. et al.; Harness, Dickey & Pierce, P.L.C., P.O. Box 828, Bloomfield Hills, MI 48303 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: BATTERY MONITOR AND METHOD



(57) Abstract

A battery monitor (10) which monitors the operating parameters of a battery (12) to provide an indication of, for example, the absolute state of charge, the relative state of charge, and the capacity of the battery (12) under battery discharge, rest, and recharge conditions. The battery monitor (10) includes a current sensor (18) for sensing battery current, a voltage sensor (20) for sensing battery voltage, and a temperature sensor (22) for sensing battery temperature. A processor (26) approximates to a high level of accuracy the battery parameters utilizing an iterative process based upon predetermined relationships, employing empirically determined constants and parameters determined in the immediately preceding iteration stored in memory (28, 30, 33). Output signals (32, 16) indicative of the determined parameters are provided and may be utilized for many different battery applications.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia
AT	Austria
AU	Australia
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CS	Czechoslovakia
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgystan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakhstan
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam

BATTERY MONITOR AND METHOD

Field of the Invention

The present invention is generally directed to battery state-of-charge determination, and more particularly, to a monitor and method for making run-time prediction.

BACKGROUND OF THE INVENTION

Lead-acid storage batteries have become highly refined since these devices were first used commercially about 125 years ago. Since its introduction, the lead-acid storage battery has distinguished itself as a highly efficient and reliable electrochemical energy source. Lead-acid storage batteries are also relatively insensitive to debilitating temperature effects over a broad temperature range of, for example, -40° to about 160° F. As a result, lead-acid storage batteries lend themselves to a broad range of utilities which continues to increase.

Transportation is one example of a commercial use for lead-acid storage batteries. Such batteries have been used for small or personal vehicle movement for quite some time. For example, such batteries have been used effectively for golf carts, wheelchairs, trolling motors or similarly small-scaled transportation devices. There has also been great interest recently in the adaptation of such storage batteries as a motive power source to larger vehicles such as the so-called "electric car." Such vehicles rely heavily upon the regenerative ability of lead-acid storage batteries to provide adequate power for transportation over reasonable distances, as for example, 50 miles, without the need for recharging. For such applications, it is of obvious importance to the user that a destination be reached prior to the need to recharge or replace the batteries. Currently, because of the rarity of electric vehicles for general transportation, facilities for recharging such batteries are uncommon and hence, travel must be carefully scheduled and monitored. In turn, there is a compelling need for monitoring the state of charge of the battery or batteries to provide an accompanying fuel gauge like indication of the amount of energy remaining in the battery or batteries for continued travel.

Another example of commercial use of lead-acid storage batteries in in the field of uninterruptable power supply (UPS). In, for example, computer and telecommunications applications it is very important that the supply of electrical power not be interrupted. Loss of electrical power may result in lost

date and interruption of vital communication resources. Unfortunately, partial or complete interruptions of electrical power delivered by utility companies are common. To gaurd against potential problems associated with power supply interruptions, telecommunications companies, for example, employ battery technology to provided uninterrupted power. As will be appreciated, however, battery UPS is capable of providing adequate power to operate electrical equipment for only a finite period of time. More importantly, the operator of the equipment needs to how long the UPS will provide power and when it will be exhausted so that vital data may be saved prior to total power loss.

There have been a number of proposals in the prior art for providing monitoring of batteries. One arrangement examines the condition of a storage battery used as a starting, lighting and ignition battery for an internal combustion engine. This arrangement measures battery voltage under open circuit conditions and while the battery is subjected to a predetermined AC load and a predetermined DC load. The temperature of the battery is also monitored. A microprocessor uses the open circuit potential, the measured potential under both DC and AC loading, and the temperature to ascertain the characteristics of the battery. The internal resistance is determined and should it be found excessive, the battery is deemed defective. Open circuit voltage, internal resistance and temperature provide inputs for calculating the estimated power at a fully charged state. The apparatus then discharges the battery through a reference load for about 15 seconds at constant load and measures a 15 second battery voltage. This voltage is then compared to a similar voltage of a battery at about a 75% state of charge under the same conditions. If the voltage measured is higher than a value stored in the apparatus, the battery condition is deemed good. As a result, performance benchmarks are ascertained with a view toward determining battery capability.

Another arrangement concerns an apparatus for determining the general state of charge of a battery. This approach, however, requires the battery to be taken off-line from its circuit and connected to a calibrated resistor to determine state of charge. The process requires the battery to be subjected to two loads, one corresponding to a minimum current consumption level or load and the other a maximum consumption level or load. The process includes monitoring the load condition between the minimum and maximum load

possibilities, periodically connecting the battery to a reference load when the minimum load is applied to the battery sampling the voltage across the reference load, and comparing the sample voltage to an array of predetermined levels, each level corresponding to a different state of charge. The comparison thereby yields an indication of the present condition of the battery.

A further arrangement determines state of charge of a battery based upon the integration of current. During the first portion of the discharge, the state of charge is evaluated by integrating the current after compensating for the rate of discharge. Later in the discharge, the state of charge of the battery is determined from the lowest subpack voltage corrected for polarization. Battery polarization it is used to calculate a corrected battery voltage which is used to terminate discharge at an appropriate time.

A more improved battery monitor is shown and described in U.S. Patent No. 4,876,513 which is assigned to the Assignee of the present invention. This monitor is a dynamic state of charge indicator for a storage battery characterized by a discharge curve relating available energy of the battery to a contemporaneous voltage over a range of voltage boundaries having predetermined end points corresponding to fully charged and effectively discharged for one charge cycle. The indicator includes a microprocessor which stores predetermined relationships between the contemporaneous voltage and the state of charge of the battery. A voltage sensor and a current sensor are connected to monitor battery voltage and current flow and to provide corresponding voltage and current signals to the microprocessor. The microprocessor periodically computes the internal resistance of the battery, the average voltage and current for a predetermined discharge time period and a corrected voltage as a total of internal resistance voltage loss and average voltage with the state of charge being determined as a function of corrected battery voltage.

U.S. Patent No. 5,321,627 which is assigned to the assignee of this application, discloses a further battery monitor and method which derives a plurality of parameters related to the state of the battery, such as relative state of charge, absolute state of charge, a "time to empty" which gives a prediction as to when the battery would be completely discharged, and a "time to full" which gives a prediction as to when the battery would be fully charged. These

parameters are calculated on the basis of sensed battery current, voltage, temperature and elapsed time. Different branches of a program are used by the processor depending on whether the battery is in a charge mode, a discharge mode, or a state of rest. The algorithm employed in the '627 patent uses a capacity adjustment step and works best for a set current load.

A need therefore continues to exist for a battery monitor and method which incorporates a programmable low voltage cutoff so that the monitor may be suited for different applications, which will give a more accurate measurement of capacity, relative state of charge and absolute state of charge, and which will give a better run-time estimate or prediction of "time to empty".

Summary of the Invention

The present invention provides a battery monitor for monitoring operating parameters of a battery. The battery monitor includes a voltage sensor and a current sensor for sensing and generating signals based on battery voltage and battery current, respectively. A processor of the monitor is coupled to the voltage and current sensors and furthermore has an input for the receipt of a low voltage cutoff signal. The processor determines when the battery is in a stage of discharge and computes, as a function of the sensed voltage, the sensed current and the low voltage cutoff, a relative state of charge, an absolute state of charge and a period until the battery will be discharged below a predetermined level. An output means, such as a buffer for a display, is provided for outputting signals indicative of predetermined ones of the operating parameters.

Preferably, under certain conditions the relative state of charge is calculated as a multiple-order polynomial function of an intermediate relative state of charge variable, the intermediate relative state of charge variable in turn being calculated as a function of the sensed voltage, the low voltage cutoff and sensed current.

According to another aspect of the invention, the processor calculates a first capacity variable during a recharge cycle and a second capacity variable during a discharge cycle. When the battery is in a state of discharge, the second capacity variable is computed as a function of the first capacity variable. When the battery enters a state of recharge, the last stored second capacity variable is used to calculate the first capacity variable. In this

manner, the monitor has the ability to "learn" and to track a variable capacity rather than using a static and predetermined battery capacity.

According to another aspect of the invention, the monitor includes a temperature sensor for sensing battery temperature and producing a battery temperature signal in response thereto. A current capacity of the battery is computed by the processor as a multiple order polynomial function of the battery temperature.

A principal technical advantage of the invention is the capability of providing a selectable low voltage cutoff for each different intended use of the battery. The present invention incorporates a new curve-fitting technique for temperature compensation in the determination of battery capacity. The capacity calculation has a learning capability; during discharge, the capacity is updated and stored for a subsequent discharge. This improves the accuracy of the monitor especially at low temperatures. Finally, the monitor of the present invention gives a more accurate "time to empty" prediction.

Brief Description of the Drawings

Other aspects of the present invention and their advantages will be discerned by reviewing the following detailed description when taken in conjunction with the drawings, in which like characters identify like elements, and in which:

FIGURE 1 is a schematic block diagram illustrating the principal components of a battery monitor in accordance with a preferred embodiment the present invention;

FIGURE 2 is a flow diagram illustrating a preferred manner in which the battery monitor of FIGURE 1 may be implemented for monitoring a battery in accordance with the present invention;

FIGURE 3 is a flow diagram of a preferred main operational subroutine of a processor employed in the invention;

FIGURES 4a and 4b together comprise a flow diagram of a preferred subroutine used when the monitored battery is in a state of discharge; and

FIGURE 5 is a flow diagram of a preferred subroutine used when the monitorized battery is in a state of recharge.

Detailed Description of a Preferred Embodiment

FIGURE 1 illustrates, in block diagram form, a battery monitor 10 embodying the present invention. The battery monitor 10 is associated with a battery 12, such as a lead-acid battery, and a load 14, which may be a varying load, such as in UPS type applications. The battery monitor 10, at spaced apart time intervals, measures the current, voltage, and temperature of the battery 12, and responsive to these measured quantities, provides output signals indicative of the operating characteristics of the battery 12 at an output 16, which may be connected to a display (not shown) and/or which may be used as a control signal to e.g. initiate load disconnect or cutover to an alternative power source. The output signals may include signals indicative of, for example: (a) a relative state of charge (RELSOC) of the battery which is the percentage of battery capacity immediately available at a specified discharge rate, such as a 15 mininute rate; (b) an absolute state of charge (ABSOC) of the battery which is the percentage of battery capacity the battery has based upon a greater than 100 hour discharge rate; (c) an output battery capacity which is the amount of amp-hours that the fully charged battery has if discharged at a specified discharge rate, such as the 15 minute rate; (d) an output "time to empty" (TTE) of the battery which is the time remaining until the battery reaches a customer selectable low voltage cutoff (LVCO), such as 10.499 volts, if discharged at a specified discharge rate, such as the present current level. The battery monitor 10 generally includes a current sensor 18, a voltage sensor 20, and a temperature sensor 22 all connected to a processor 26. A timer 24, a processor 26, a read-only memory 28, a random-access memory 30 and an output means 32 are also connected to processor 26. Output means 32, which may include digital to analog conversion, buffering and/or a communications interface, provides parameter output signals at output 16. A programmable read-only memory (PROM) 33 may be provided to store information that is configured at the factory for the user. This information can include any of various operational constants, and advantageously may include a low voltage cutoff (LVCO) constant that will vary according to the application of the battery. Alternatively or in addition, a user terminal 35, which for example may consist of a simple keypad, may be provided for the entry by the user of LVCO and other operational constants. PROM 33 and terminal 35 have their outputs connected

to respective input terminals of the processor 26, either directly or by means of data and address buses as is well known in the art.

The current sensor 18 is coupled in series between the battery 12 and the load 14 for sensing the current drawn from the battery 12 and may be of any form well known in the art for sensing a current within a circuit. The voltage sensor 20 is coupled across the battery 12 for sensing the output voltage of battery 12 and may be of any form well known in the art for sensing the voltage of a power source. The temperature sensor 22 may be of any form well known in the art for sensing the temperature of the battery. Alternatively, for those applications where the temperature of the battery is to be maintained at a known constant level, the temperature sensor 22 may be omitted and a fixed temperature used for generating a battery temperature signal to processor 26.

The timer 24 initiates computing times and causes the processor 26, at spaced apart time intervals, to read the voltage sensor signal from sensor 20, the temperature sensor signal from sensor 22, and the current sensor signal from sensor 18, and based on these signals, the low voltage cutoff, certain predetermined constants and the algorithm described below, provides the output means 32 with intermediate control signals indicative of the output parameters. The intermediate control signals may be multiple bit binary words which are converted to analog signals by a digital to analog converter (not shown) of the output means 32, for example. Although the timer 24 is shown external to the processor 26, as well known in the art, the timer 24 may be included within the processor 26 without departing from the present invention.

Alternatively, the battery monitor may initiate computing times through a different mechanism. For example, the processor may initiate the computing time at the completion of the last read operation. In these cases, the timer 24 would be coupled to the processor 26 to indicate the time elapsed between consecutive iterations: in this embodiment, the timer 24 would indicate the time it took to complete the last iteration. Preferably, the timer 24 supplies a day number, hour, minute and second value to the processor 26. The processor 26 converts these values into various time-related variables used in determining watt hours remaining and ampere hours remaining as will be described below.

The processor 26 may take different forms. For example, the processor 26 may be a digital signal processor, a microprocessor, a

microcontroller, or a general purpose computer. The processor 26 obtains operating instructions from ROM 28 via a multiple-bit bus 34 to control its executions for generating the intermediate control signals in a manner to be described hereinafter.

The random-access memory (RAM) 30 is coupled to the processor 26 by a multiple-bit bidirectional bus 36.

The battery monitor 10 uses iterative processing for determining the operating parameters of the battery. RAM 30 is used for storing constants retrieved from ROM 28, signal LVCO from (e.g.) PROM 33, and the operating parameters computed by the processor 26 during its last iteration. Certain of these stored parameters are used by the processor 26 to determine the operating parameters of the battery 12 during the next iteration. In addition, the RAM 30 may also be used by the processor 26 for storing last measured values such as the current of the battery (CURR) measured during this iteration. Each such sensed or measured value or operating parameter stored in the second memory 30 will therefore be referred to hereinafter as the last corresponding measured value or computed parameter. For example, in implementing the battery monitor 10, during each iteration, the microprocessor stores two parameters related to the newly calculated capacity of the battery, the relative state of charge of the battery, the absolute state of charge of the battery, a factor to be described hereinafter, and the current of the battery.

As will be seen hereinafter, the relationships implemented by the processor 26 between the sensed current, sensed voltage, and sensed temperature of the battery provide a very accurate approximation of the operating parameters of the battery 12 under all conditions including discharge and recharge of the battery. These relationships require the use of a number of empirically determined constants. These constants, and the manner of empirically deriving the same, are discussed immediately hereinafter.

Constants "g", "h" and "i" are empirically derived constants used in a curve-fitting technique which employs the battery temperature in order to calculate a non-temperature-corrected remaining capacity (RCAP) and a beginning temperature corrected rated capacity (RATEDCAP) as a function of an initial rated capacity (RATEDCAPINI) as multiplied by a multiple-order polynomial function of the battery temperature.

Constants "PEB", "PEC" and "PED" are empirically derived multipliers for a current variable (PCURR) and are used to calculate RCAP in conjunction with temperature.

Constants "a", "b", "c", "d", "e", and "f" are empirically derived multipliers used in conjunction with measured current in the calculation of an intermediate state of charge variable, FGRELSOC, that in turn is used for the calculation of relative state of charge.

Constants "aaa", "bbb", "ccc", "ddd", "eee", "fff", "ggg", "hhh" and "iii" are empirically derived multipliers of various terms in a multiple-order polynomial function for the calculation of a factor (FACTOR), itself used in the calculation of relative state of charge.

Constant "gsb" is a battery limit, measured in volts, above which a gassing current is generated during recharging the battery. At gsb volts and above, a portion of the recharging current is not recharging the battery. The constant "gsb" is used in the calculation of WGASFACTOR, an efficiency multiplier which varies according to the sensed voltage of the battery.

Constant LVCO is a low-voltage cutoff preferably selected by the manufacturer according to the intended application of the battery.

The following is a list containing typical values for the constants described above

for a typical 30 amp-hour telecommunitions UPS battery manufactured by Johnson Controls, Inc., the assignee of the present invention.

<u>Table of Constants</u>

g	=	0.79156
h	=	0.0109697 $^{\circ}F^{-1}$
i	=	-1.12389×10^{-4} $^{\circ}F^{-2}$
PEB	=	.190707 h
PEC	=	-0.003722 $(\text{amps})^{1/2}$-h
PED	=	-4.201923
a	=	0.008797 ohms
b	=	241.0829
c	=	-0.073599 watts
d	=	0.008354 amps^{-1}
e	=	271.0421 amps
f	=	0.042262 amps
aaa	=	-5.32×10^{-5}
bbb	=	-3.8969
ccc	=	0.0073805
ddd	=	5.51927
eee	=	-0.12919
fff	=	-3.08845
ggg	=	0.491905
hhh	=	1.346428
iii	=	0.5103199
gsb	=	13.8 volts
LVCO	=	10.499 volts

FIGURES 2-5 are flow diagrams of the operation of processor 26 according to the invention, with FIGURE 2 illustrating the main operating program of the invention and FIGURES 3-5 illustrating various subroutines thereof. The programs starts at step 100 and initializes the program's variables and constants at step 102. The constants are read from read-only memory 28 or PROM 33 and are stored in random access memory 30. These constants are listed in the Table of Constants given above. Also at this step, the variables used in the algorithm according to the invention are initialized. Certain of these initialized variables are given in the table immediately below. They include the absolute state of charge (ABSOC) and the relative state of charge (RELSOC); an initial rated capacity RATEDCAPINI, a rated capacity RATEDCAP and a further capacity calculation variable RCAP; a rated current variable RAMP, initialized as -.01 of RATEDCAPINI,

and measured in amperes; and a flag variable CHGFLAG designed to switch the algorithm to recharge or discharge subroutines depending on its value.

Table of Initialized Variables

ABSOC	=	1
RATEDCAPINI	=	37.1183 amp-h
RATEDCAP	=	37.1183 amp-h
RAMP	=	-0.371183 amperes
RELSOC	=	1
CHGFLAG	=	2
RCAP	=	37.1183 amp-h

At step 104, constant LVCO is read (in one embodiment) from PROM 33, and a timing variable "st" is read from the timer 24. At step 106, the voltage is sensed from the volt sensor 20, the current of the battery is sensed from the current sensor 18, and the battery temperature is sensed from the battery temperature sensor 22. These become the values for variables VOLT, CURR and BATTEMP, respectively.

At step 108, a variable TIME is calculated as a function of the time st read at step 104. In a preferred embodiment, variable TIME is calculated by going to a subroutine that reads hours, minutes and seconds, and adds twenty-four hours for each day that has elapsed. The returned variable is denominated in hours.

At step 110, the main program enters a subroutine MONITOR for making the time to empty predication which is illustrated in detail in FIGURE 3. At step 112 in FIGURE 3, an elapsed time DELTIME is calculated by subtracting the read time from the last stored time. A power variable WATT is calculated at step 114 as the product of CURR and VOLT. At step 116, a current variable PCURR is calculated as the negative of CURR; PCURR is used in a pair of polynomial expressions in which the square root and a fractional exponent of this variable are calculated.

At step 118, the number of watt-hours remaining (WHREM) and the number of ampere-hours remaining (AHREM) are calculated by taking the last stored values of WHREM and AHREM, respectively, and adding (or subtracting) an increment. In the case of WHREM, the power consumed (or added back to the battery) is multiplied by the elapsed time DELTIME, and this amount is added to the last stored WHREM. Similarly, for AHREM, the amount of elapsed time

DELTIME is multiplied by the current CURR, and this value is added to the last stored value for AHREM and then restored in memory 30. If the battery is in a discharge mode, the current will be negative and the number of ampere hours remaining will decrease; if the battery is in a recharge mode, variable AHREM will increase.

At step 120, the program tests where the battery current CURR is below the value RAMP. It will be recalled that RAMP is initialized as a small negative value. If the current CURR is beneath this value, it indicates that the battery is in discharge mode, and the program branches to subroutine DISCHARGE at step 122. If the value for current CURR is above this value, the program branches to subroutine RECHARGE at step 124.

Subroutine DISCHARGE is illustrated in detail in the flow diagram started in FIGURE 4a. At step 126, a first temperature-corrected rated capacity variable RATEDCAP is calculated as a function of the initial rated capacity RATEDCAPINI times a multiple-order polynomial expression of the battery temperature BATTEMP, preferably a second-order polynomial expression as shown. At step 128, the temperature-corrected rated capacity RATEDCAP is used to calculate a current capacity variable CRNTCAP. This step uses PCURR, $PCURR^{1.5}$ and $PCURR^{0.5}$, as respectively multiplied by empirically derived constants PEB, PEC and PED, to calculate CRNTCAP. The expression in step 128 calculates CRNTCAP according to a curve that has been fitted to empirically derived data. Similarly, the temperature correction performed at step 126 uses a two-order polynomial expression to fit the calculation to a curve of empirically observed data.

At step 130, the sensed voltage VOLT is tested against the low voltage cutoff LVCO. If the voltage is above the low voltage cutoff, then an intermediate relative state of charge variable FGRELSOC is calculated as a function of VOLT, LVCO and CURR. This function is a multiple order polynomial expression and is given in Equation 1 below:

$$FGRELSOC=\left(\frac{VOLT-LVCO}{a(b+CURR)+\frac{c}{CURR}}\right)^{\left(d(e+CURR)+\frac{f}{CURR}\right)} \tag{1}$$

Once again, this expression fits the calculation of FGRELSOC to a curve of empirically derived data. If the voltage is below the low voltage cutoff,

then 0 is instead assigned to the variable FGRELSOC at step 134.

Both branches proceed next to a step 136 which calculates a factor FACTOR as a polynomial expression of FGRELSOC. Preferably, this polynomial expression is fourth-order. A preferred polynomial expression is given below:

$$FACTOR=\frac{aaa+cccFGRELSOC+eeeFGRELSOC^{2}+gggFGRELSOC^{3}+iiiFGRELSOC^{4}}{1+bbbFGRELSOC+dddFGRELSOC^{2}+fffFGRELSOC^{3}+hhhFGRELSOC^{4}} \quad (2)$$

At decision step 138, the relative state of charge RELSOC is tested against 0.85. In the first pass through the program, the relative stage of charge RESLOC will be 1.0, and therefore the program will branch to step 140 in which the relative state of charge is calculated as $\frac{CRNTCAP+AHREM}{CRNTCAP}$. If RELSOC is below 0.85, then RELSOC is calculated as a function of the last stored RELSOC plus a factored component of the last stored FGRELSOC at step 142, as shown. As an artifact of these calculations, RELSOC may be assigned a negative number; in this event, at step 144, RELSOC is limited to 0 or above.

At step 146, a variable for the amount of state of charge that has been used (SOCUSED) is calculated as a function of the last sensed current (CURR), the lapsed time DELTIME and the temperature-corrected capacity RATEDCAP. The program then continues to FIGURE 4b through connector 148.

Referring to FIGURE 4b, at step 150 variable SOCUSEDTOT, which is representative of the total or cumulative stage of charge used, is tested against 0.05. If SOCUSEDTOT is greater than 0.05, a further decision block 152 is reached in which the sensed voltage VOLT is compared with the retrieved low voltage cutoff LVCO. If the answer is yes, a further capacity variable RCAP is calculated at step 154 as a curve-fitting multi-order polynomial expression of AHREM, RELSOC, PCURR AND BATTEMP:

$$RCAP=\frac{\frac{-ahrem}{1-RELSOC}-(PEB(PCURR)+PEC(PCURR)^{1.5}+PED(PCURR)^{0.5})}{g+hBATTEMP+iBATTEMP^{2}} \quad (3)$$

If SOCUSEDTOT is less than or equal to 0.05 or the sensed voltage is not greater than LVCO, the calculation of RCAP is bypassed. Both program paths converge to step 156, which computes "time to empty" (TTE) as a product of RELSOC, CRNTCAP and the reciprocal of CURR. If by this calculation, TTE as

calculated is less than 0, then TTE is limited to 0 at step 158. At step 160, the total state of charge used (SOCUSEDTOT) is incremented. At step 162, the absolute state of charge ABSOC is calculated as 1-SOCUSEDTOT, such that the absolute state of charge and the total state of charge used will always sum to 1. At step 164, the subroutine flag CHGFLAG is set to 0 to indicate that the battery is in a discharge mode or state. The program returns at step 166.

Returning momentarily to FIGURE 3, if the sensed current CURR is greater than RAMP at step 120, the program determines that the battery is in a recharge mode, and subroutine RECHARGE is entered at step 124. This subroutine is illustrated in detail in FIGURE 5. At step 170, the program ascertains whether CHGFLAG is greater than or less than 1; if so, it indicates that the RECHARGE mode has just been entered. In this instance, the variable RATEDCAPINI is set to the variable RCAP at step 172. If the battery had just left a discharge mode, by this step a calculated or "learned" and temperature corrected rated capacity is used in this and subsequent consecutive RECHARGE cycles. In either event, the program proceeds to step 174 in which the variable CRNTCAP is reset to RATEDCAPINI. At decision step 176, the sensed voltage VOLT is compared against a gassing voltage limit gsb. If VOLT is above gsb, which in one embodiment is set at 13.8 volts, a gassing current factor WGASFACTOR is calculated at step 178 as a function of the sensed voltage VOLT and gsb. Otherwise, at step 180 WGASFACTOR is set to 1.

Next, at step 182, the used state of charge SOCUSED is calculated as a product of the current, WGASFACTOR and the elapsed time DELTIME, as divided by the temperature-corrected rated capacity RATEDCAP. The value of variable RATEDCAP is carried over from the discharge mode, in which it is calculated as a multiple-order polynomial of the initial rated capacity RATEDCAPINI and the battery temperature BATTEMP. At step 184, the total state of charge used SOCUSEDTOT is decremented by adding SOCUSED to it, because in this instance SOCUSED will be a negative number. The absolute state of charge ABSOC is calculated at step 186. If ABSOC is calculated as greater than 1, it is limited to 1 at step 188. At step 190, variable TTE is set to ABSOC for display purposes only, and the relative state of charge variable RELSOC is set to ABSOC as well. At step 192, the mode flag CHGFLAG is set to 1 to indicate that the program has just exited a recharge cycle and an iteration of the RECHARGE subroutine and control

is returned to subroutine ENERGYEYE at step 194. Notice that RATEDCAPINI, as last calculated by subroutine RECHARGE, is used in the next encountered cycle of subroutine DISCHARGE to calculate a temperature corrected rated capacity RATEDCAP. In this way, stored and updated values of the battery capacity are used in subsequent iterations to give a more accurate idea as to the actual battery capacity.

Returning to FIGURE 3, the next step in subroutine ENERGYEYE is a decision step 196, which compares RELSOC to ABSOC. If RELSOC is greater than ABSOC, then the program branches to step 198 at which the total state of charge used (SOCUSEDTOT) is recalculated and the absolute state of charge ABSOC is set to relative state of charge variable RELSOC. Otherwise, the program branches directly to step 200 to limit SOCUSEDTOT to greater than or equal to 0. At step 202, variable ABSOC is limited to between 0 and 1, inclusive. The variables are stored for the next iteration at step 204, and control is returned to the main program at step 206.

Returning to FIGURE 2, selected ones of the calculated variables or parameters are output at step 208 using the output means 32. These parameters are output in order to give the user an indication of the state of the battery, and may include the absolute state of charge ABSOC, the relative state of charge RELSOC, a number of ampere-hours remaining AHREM, a "time to empty" TTE, and other parameters as desired, such as voltage, current and battery temperature. The program then loops back to read the next sensed voltage, current and battery temperature at step 106.

In summary, an improved apparatus for determining and displaying the run-time of the battery has been illustrated and described. A low voltage cutoff variable, which is selected by the user, is incorporated into the run-time calculation. The battery capacity is calculated according to functions fitted to curves of empirically-derived data relating to sensed current, battery temperature and other variables.

While a preferred embodiment of the invention has been described in the above detailed description and illustrated in the accompanying drawings, the invention is not limited thereto but only by the scope and spirit of the appended claims.

WHAT IS CLAIMED IS:

1. A battery monitor for monitoring operating parameters of a battery, comprising:

a voltage sensor for sensing a battery voltage of the battery and outputting a voltage sensor signal in response thereto;

a current sensor for sensing a battery current of the battery and outputting a current sensor signal in response thereto;

a processor coupled to receive the voltage sensor signal, the current sensor signal and a low voltage cutoff signal;

a memory coupled to the processor for storing selected ones of the operating parameters and values of the voltage sensor signal, the current sensor signal and the low voltage cutoff signal; and

the processor determining when the battery is in a state of discharge and computing, based upon the voltage sensor signal value, the current signal value and the low voltage cutoff signal value, (a) a relative state of charge, (b) an absolute state of charge and (c) a time period left until the battery will be discharged below a predetermined level.

2. The battery monitor of Claim 1, wherein the processor calculates an intermediate relative state of charge variable based upon the low voltage cutoff signal value, the processor using the intermediate relative state of charge variable to calculate the relative state of charge under a predetermined condition.

3. The battery monitor of Claim 2, wherein the memory stores a last calculated value of the relative state of charge, the predetermined condition including the last calculated value of the relative state of charge being in a predetermined range.

4. The battery monitor of Claim 2, wherein the intermediate relative state of charge variable is calculated as a function of the low voltage cutoff signal value and a polynomial function of the current sensor signal value under a predetermined condition.

5. The battery monitor of Claim 4, wherein the predetermined condition includes having the voltage sensor signal value within a predetermined relation to the low voltage cutoff signal value.

6. The battery monitor of Claim 2, wherein the relative state of charge is calculated as a multiple order polynomial function of the intermediate relative state of charge variable under a predetermined condition.

7. The battery monitor of Claim 6, wherein the memory is adaptable to store a last calculated value of the relative state of charge, the predetermined condition including having the last calculated value of the relative state of charge fall within a predetermined range.

8. A battery monitor for monitoring operating parameters of a battery, comprising:

a voltage sensor for sensing a battery voltage of the battery and outputting a voltage sensor signal in response thereto;

a current sensor for sensing a battery current of the battery and outputting a current sensor signal in response thereto;

a processor coupled to receive the voltage sensor signal and the current sensor signal, the processor computing operating parameters at spaced apart computing times;

a memory coupled to the processor for storing values of the voltage sensor signal, the current sensor signal and selected ones of a pluarlity of operating parameters including first and second capacity variables; and

the processor determining when the battery is in a state of discharge and then computing as a function of a last computed value of the first capacity variable, the second capacity variable, the processor determining when the battery enters a state of recharge and then computing as a function of a last computed second capacity variable, the first capacity variable.

9. The battery monitor of Claim 8, and further comprising a temperature sensor for sensing a battery temperature and outputting a battery temperature signal in response thereto, the processor coupled to receive the temperature

sensor signal, the memory adaptable to store a value of the temperature sensor signal, a third capacity variable included among the operating parameters;

the processor, during the discharge mode, computing the third capacity variable as a function of the first capacity variable and the temperature sensor signal value, the second capacity variable being calculated as a function of the third capacity variable.

10. The battery monitor of Claim 9, wherein the third capacity variable is calculated as a multiple-order polynomial function of the temperature sensor signal value.

11. The battery monitor of Claim 8, wherein a third capacity variable is included among the operating parameters, the third capacity variable being periodically calculated by the processor as a function of the current sensor signal value and the first capacity variable, the second capacity variable being calculated as a function of the third capacity variable.

12. The battery monitor of Claim 11, wherein the third capacity variable is calculated as a polynomial function of the current sensor signal value.

13. The battery monitor of Claim 8, wherein a relative state of charge is included in the operating parameters, the relative state of charge computed as a function of the first capacity variable, the second capacity variable computed as a function of the relative state of charge.

14. The battery monitor of Claim 13, and further comprising a temperature sensor for sensing a battery temperature and outputting a battery temperature signal in response thereto, the processor coupled to the temperature sensor for receiving the battery temperature signal and deriving a temperature value therefrom, the memory adaptable to store the temperature value;

the relative state of charge being computed as a function of the temperature value.

15. A method for monitoring operating parameters of a battery in monitoring cycles performed at each of a plurality of spaced-apart times, each monitoring cycle comprising the steps of:

sensing a voltage of the battery;

sensing a current of the battery;

retrieving from a memory a predetermined low-voltage cutoff;

using a processor to compute, as a function of the sensed voltage, the sensed current and the low voltage cutoff, (a) a relative state of charge, (b) an absolute state of charge and (c) a time period until the battery will be discharged below a predetermined level, the relative state of charge, absolute state of charge and time period being among the operating parameters; and

outputting signals indicative of predetermined ones of the operating parameters.

16. The method of Claim 15, and further comprising the steps of:

predetermining the low voltage cutoff according to the intended use of the battery, and

programming the memory with the predetermined low voltage cutoff.

17. A method for monitoring operating parameters of a battery in a plurality of monitoring cycles performed by a processor at respective spaced-apart times, comprising, for each cycle:

sensing a voltage of the battery;

sensing a current of the battery;

storing the sensed voltage and the sensed current;

storing selected ones of the operating parameters as calculated for the last monitoring cycle, the operating parameters including first and second capacity variables;

determining whether the battery is in a state of discharge or has entered a state of recharge;

if the battery is in a state of discharge, calculating a current value of the second capacity variable as a function of a last value of the first capacity variable; and

if the battery has entered a state of recharge, calculating a current value of the first capacity variable as a function of the last value of the second capacity variable; and

outputting signals indicative of predetermined ones of the operating parameters.

18. The method of Claim 17, and further comprising, for each monitoring cycle when the battery is in a state of discharge, the steps of:

sensing a temperature of the battery;

calculating a third capacity variable as a function of the last value of the first capacity variable and the sensed temperature; and

calculating the second capacity variable as a function of the third capacity variable.

19. The method of Claim 18, wherein the step of calculating the third capacity variable is performed as a multiple-order polynomial function of the sensed temperature.

20. The method of Claim 19, wherein the step of calculating the third capacity variable is performed as a polynomial function of the sensed current.

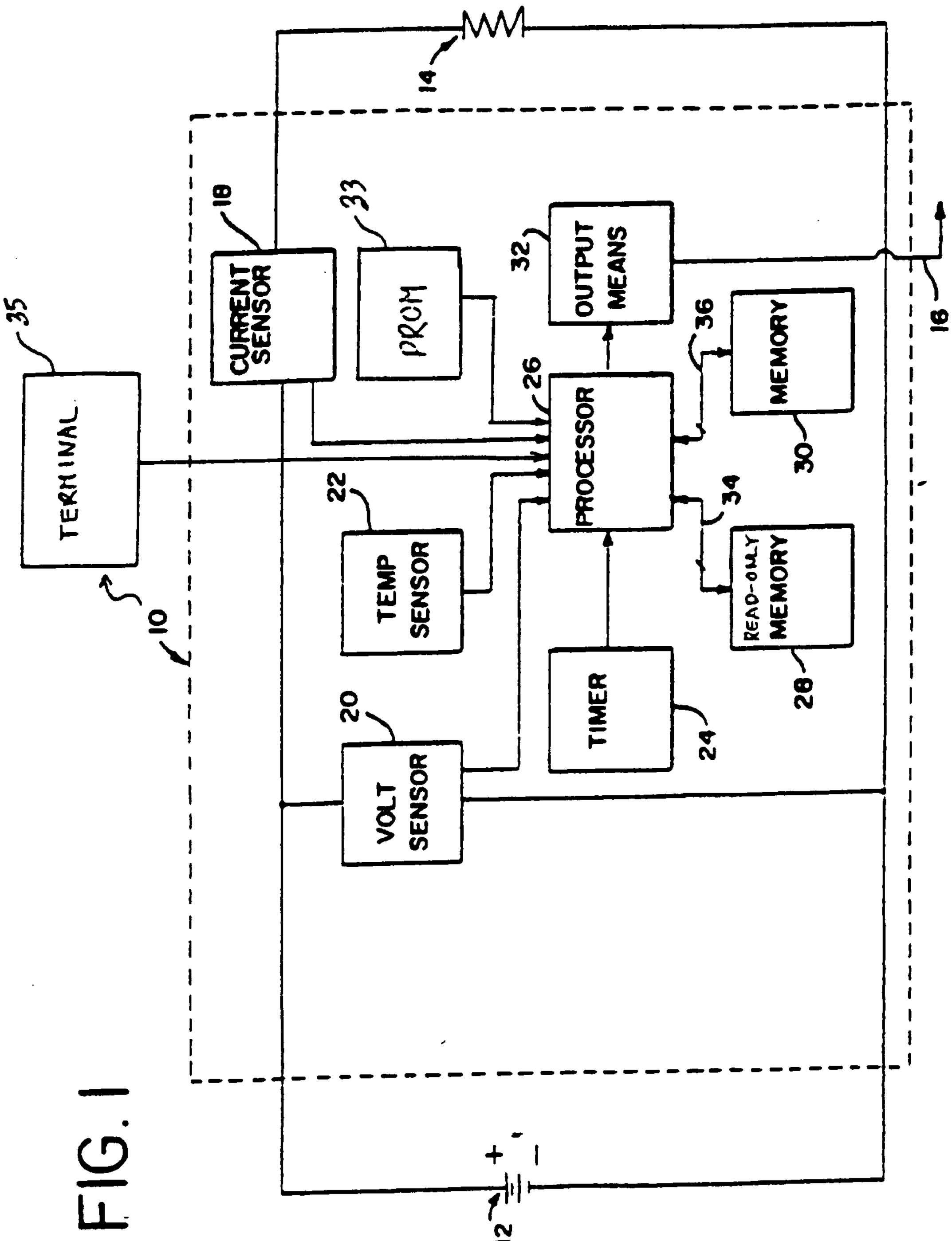

TERMINAL
35
10
CURRENT SENSOR
18
PROM
33
OUTPUT MEANS
32
PROCESSOR
26
MEMORY
30
36
34
READ-ONLY MEMORY
28
TEMP SENSOR
22
VOLT SENSOR
20
TIMER
24
14
16
12
+
-

FIG. 1

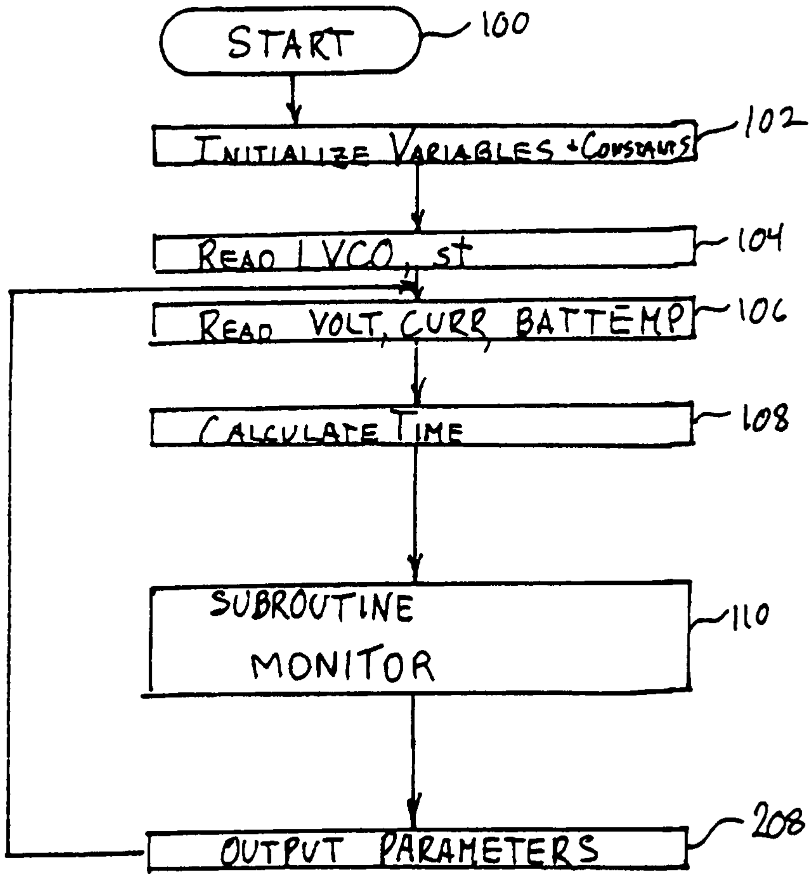

START
100
INITIALIZE VARIABLES + CONSTANTS
102
READ LVCO, st
104
READ VOLT, CURR, BATTEMP
106
CALCULATE TIME
108
SUBROUTINE MONITOR
110
OUTPUT PARAMETERS
208

FIGURE 2

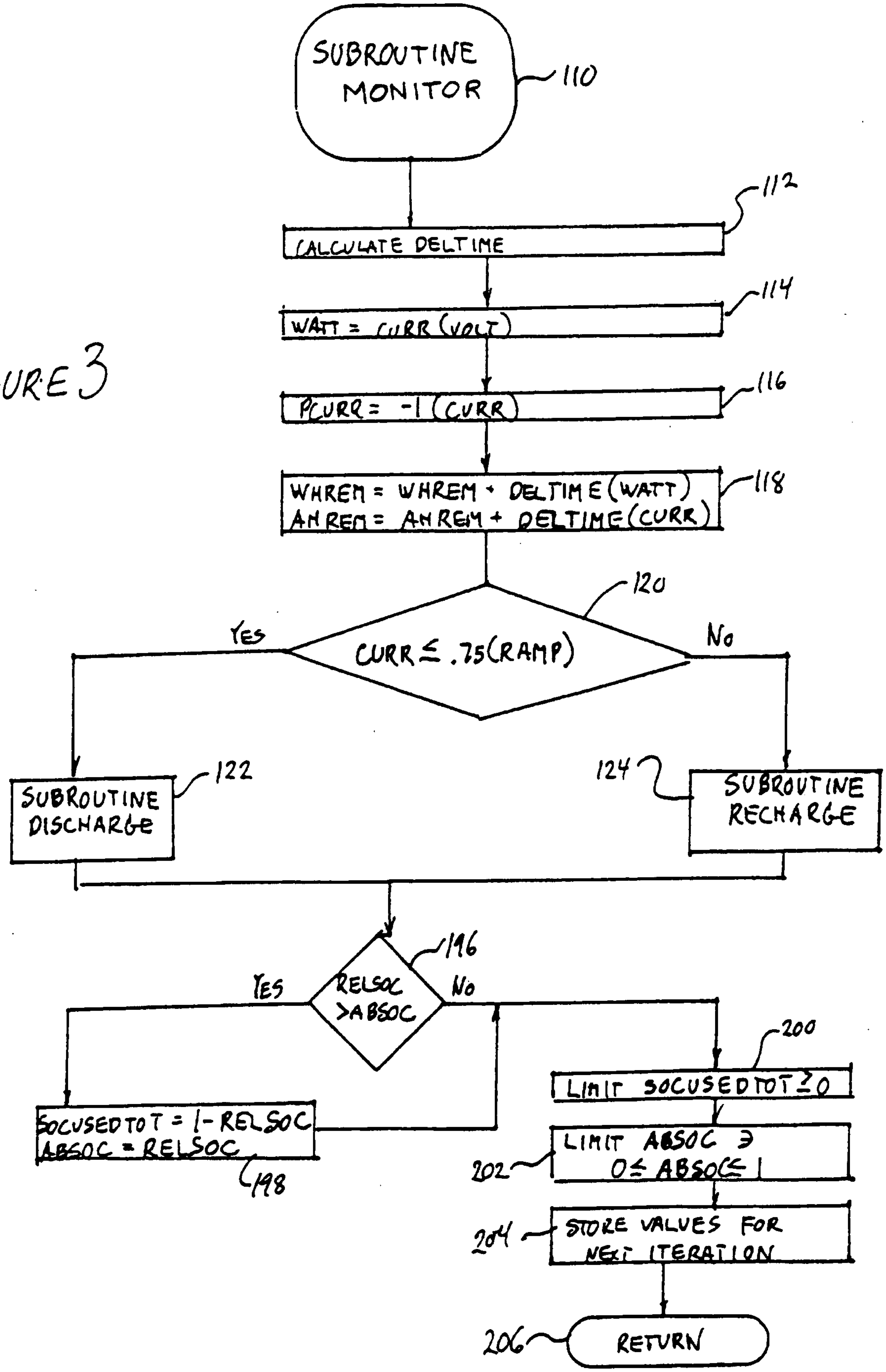

SUBROUTINE MONITOR
110
112
CALCULATE DELTIME
114
WATT = CURR (VOLT)
116
PCURR = -1 (CURR)
118
WHREM = WHREM + DELTIME (WATT)
AHREM = AHREM + DELTIME (CURR)
120
YES
CURR ≤ .75(RAMP)
NO
122
SUBROUTINE DISCHARGE
124
SUBROUTINE RECHARGE
196
YES
RELSOC >ABSOC
NO
200
SOCUSEDTOT = 1 - RELSOC
ABSOC = RELSOC
198
LIMIT SOCUSEDTOT ≥ 0
202
LIMIT ABSOC ∋ 0 ≤ ABSOC ≤ 1
204
STORE VALUES FOR NEXT ITERATION
206
RETURN

FIGURE 3

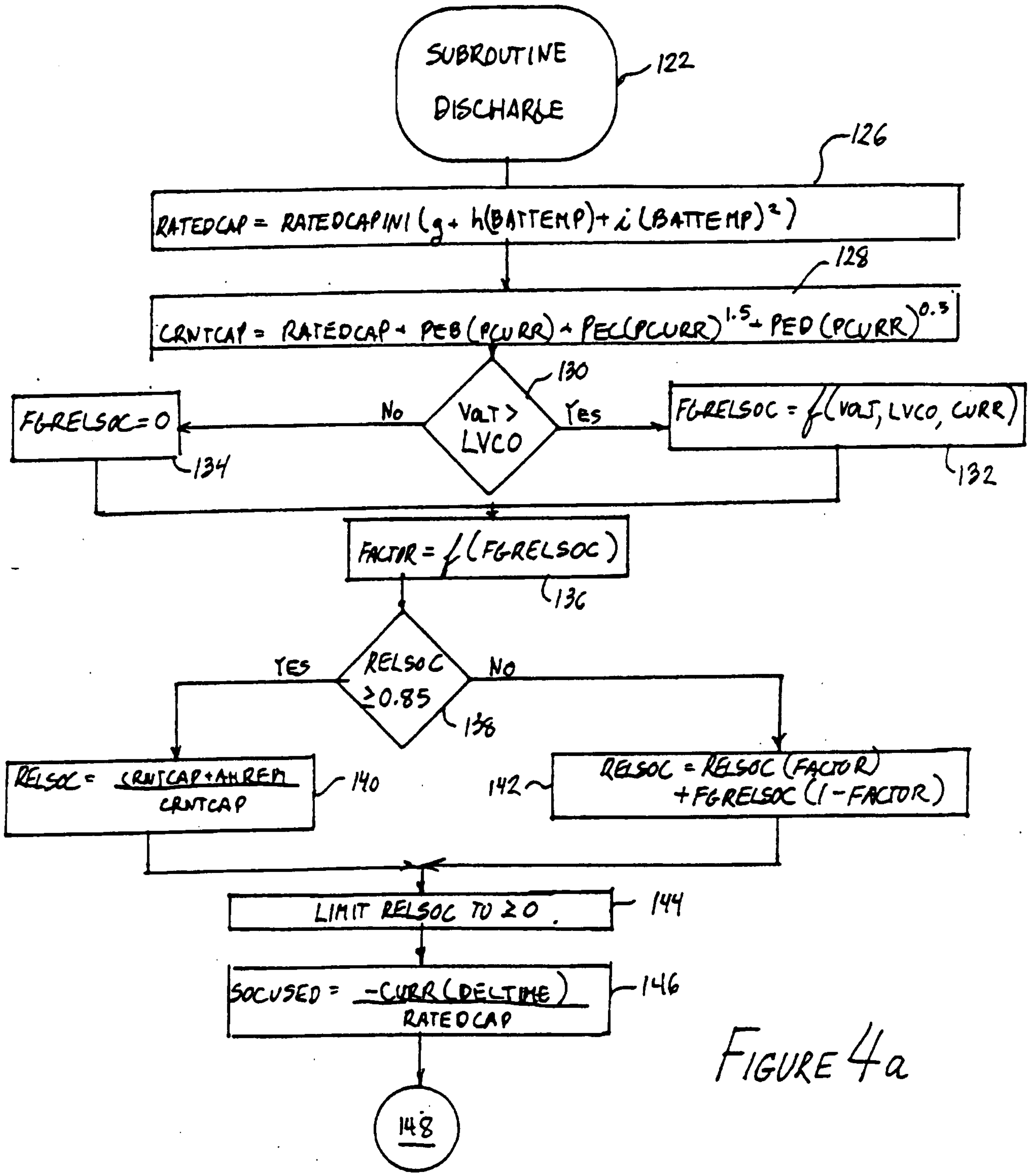

SUBROUTINE DISCHARGE
122
126
RATEDCAP = RATEDCAPINI (g + h(BATTEMP) + i (BATTEMP)²)
128
CRNTCAP = RATEDCAP + PEB (PCURR) + PEC(PCURR)^1.5 + PED (PCURR)^0.3
130
No
VOLT > LVCO
Yes
FGRELSOC = 0
134
FGRELSOC = f(VOLT, LVCO, CURR)
132
FACTOR = f (FGRELSOC)
136
YES
RELSOC ≥0.85
NO
138
RELSOC = CRNTCAP+AHREM / CRNTCAP
140
142
RELSOC = RELSOC (FACTOR) + FGRELSOC (1-FACTOR)
LIMIT RELSOC TO ≥0.
144
SOCUSED = -CURR(DELTIME) / RATEDCAP
146
148

FIGURE 4a

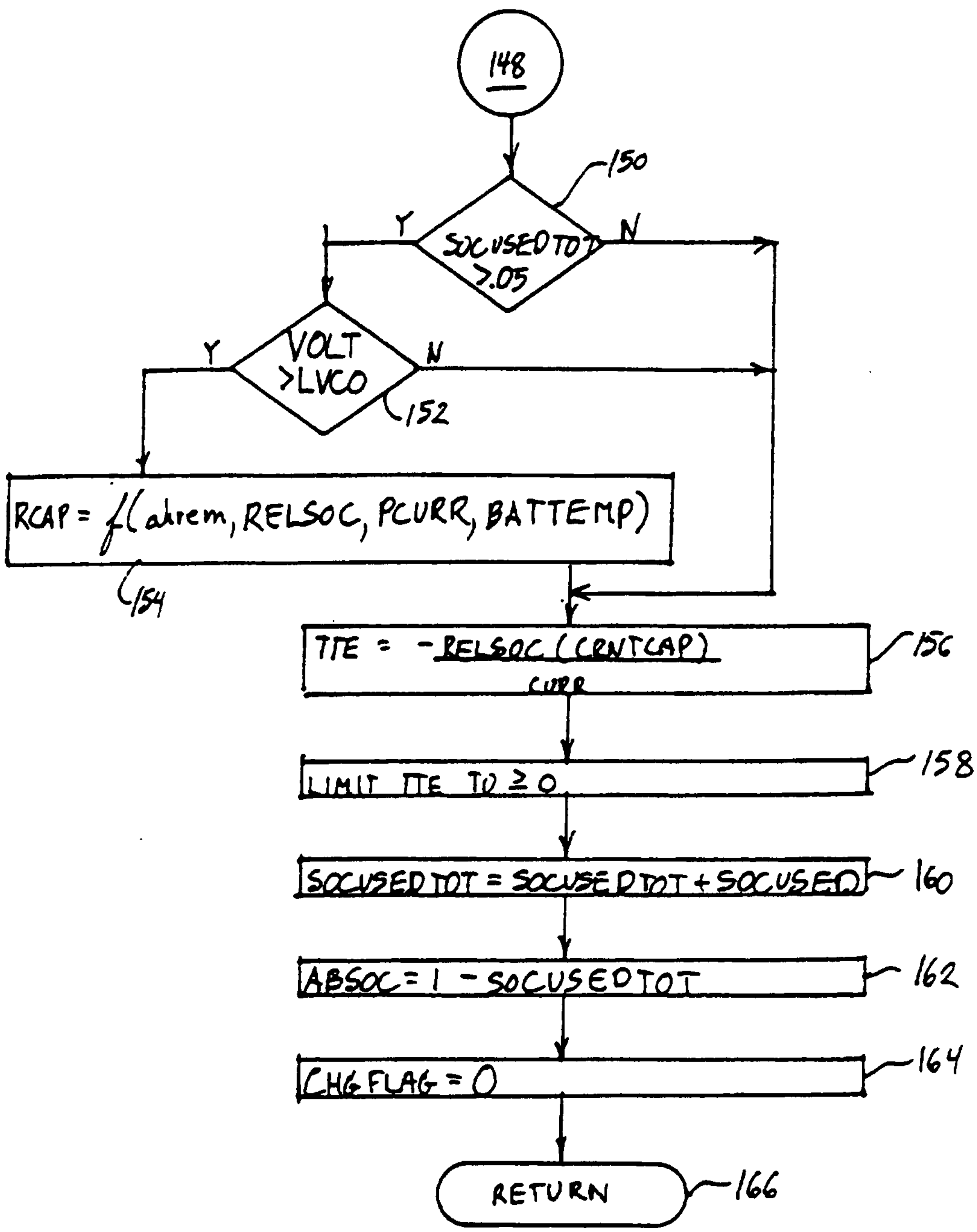
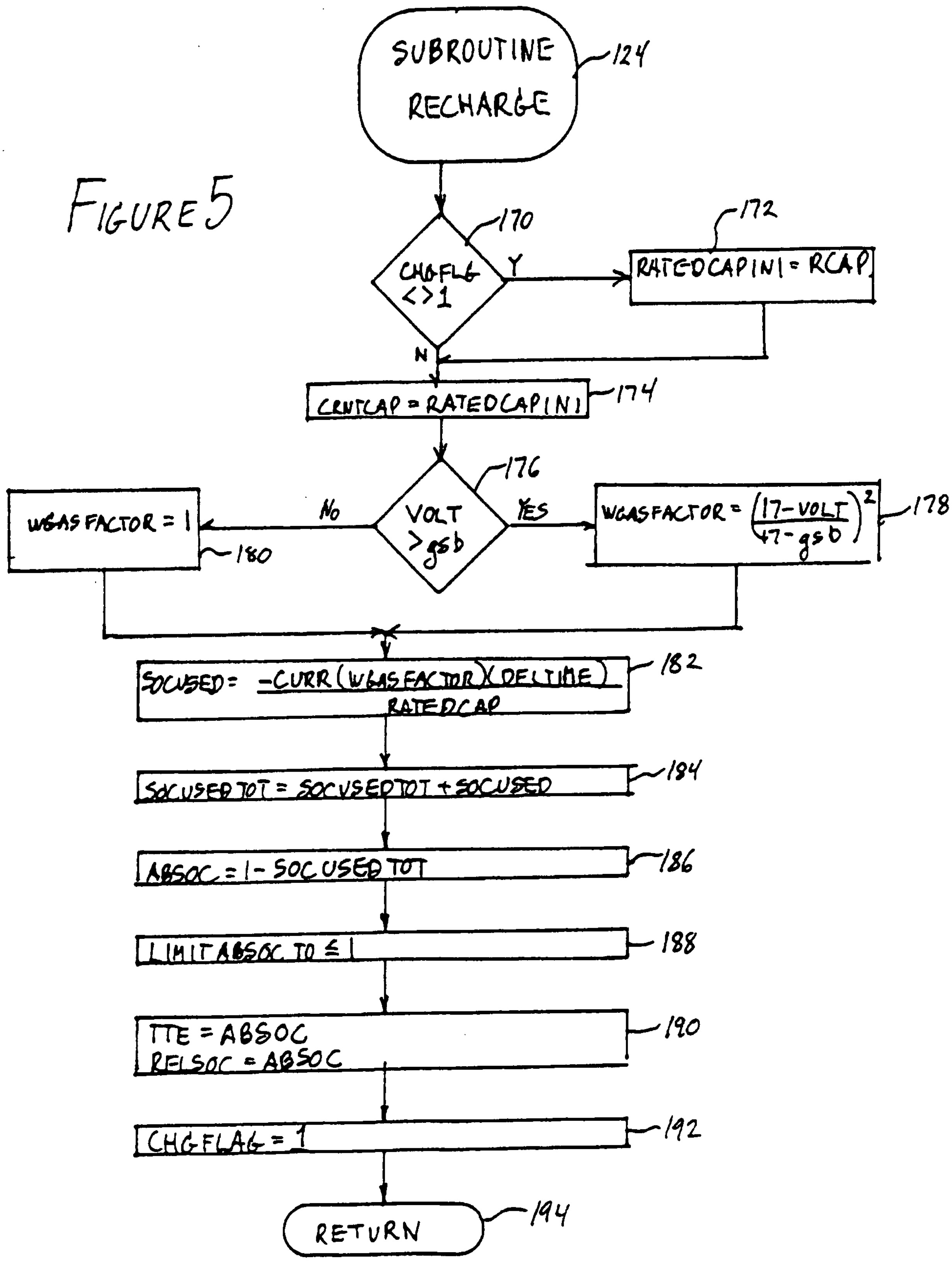

148
150
SOCUSEDTOT >.05
Y
N
VOLT >LVCO
Y
N
152
RCAP = f(ahrem, RELSOC, PCURR, BATTEMP)
154
TTE = - RELSOC (CRNTCAP) / CURR
156
LIMIT TTE TO ≥ 0
158
SOCUSEDTOT = SOCUSEDTOT + SOCUSED
160
ABSOC = 1 - SOCUSEDTOT
162
CHGFLAG = 0
164
RETURN
166

FIGURE 4b

FIGURE 5


SUBROUTINE RECHARGE
124
CHGFLG <> 1
170
Y
RATEDCAP(N) = RCAP
172
N
CRNTCAP = RATEDCAP(N)
174
VOLT > gsb
176
No
YES
WGASFACTOR = 1
180
WGASFACTOR = ((17 - VOLT)/(17 - gsb))^2
178
SOCUSED = -CURR(WGASFACTOR)(DELTIME) / RATEDCAP
182
SOCUSEDTOT = SOCUSEDTOT + SOCUSED
184
ABSOC = 1 - SOCUSEDTOT
186
LIMIT ABSOC TO ≤ 1
188
TTE = ABSOC
RELSOC = ABSOC
190
CHGFLAG = 1
192
RETURN
194

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/16797

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01R 31/36
US CL :364/492, 557; 340/636; 324/427, 431; 320/35, 48
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 364/483, 492, 550, 557; 340/636; 324/426, 427, 431, 433; 320/31, 33, 35, 48

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US, A, 5,321,627 (Reher) 14 June 1994, the abstract, Fig. 1, column 4 line 50 to column 5 line 31, column 10 lines 21-61, and column 12 line 49 to column 19 line 5.	1, 8-15, and 17-20 --------- 2-7 and 16
X	US, A, 4,876,513 (Brilmyer et al.) 24 October 1989, the abstract, Figs. 1-4, and column 3 line 46 to column 5 line 58.	1, 8, 15, and 17
X	US, A, 4,937,528 (Palanisamy) 26 June 1990, the abstract, Figs. 4-7, column 2 line 60 to column 4 line 28, and column 6 line 64 to column to column 10 line 20.	1, 8, 15, and 17
X	US, A, 4,952,862 (Biagetti et al.) 28 August 1990, the abstract, Figs. 1-2, and column 2 line 53 to column 4 line 41.	1, 8, 15, and 17

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

03 DECEMBER 1996

Date of mailing of the international search report

31 JAN 1997

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231
Facsimile No. (703) 305-3230

Authorized officer
Emanuel Todd Voeltz
for
BRIAN A. HARDEN
PARALEGAL SPECIALIST
GROUP 2400
Telephone No. (703) 305-3800

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 5,032,825 (Kuznicki) 16 July 1991, the abstract, Figs. 1-2, column 1 lines 10-55, and column 3 line 9 to column 5 line 49.	1, 8, 15, and 17
X,P	US, A, 5,371,682 (Levine et al.) 06 December 1994, the abstract and column 2 line 1 to column 5 line 2.	1, 8, 15, and 17
X,P	US, A, 5,565,759 (Dunstan) 15 October 1996, the abstract, Figs. 1A, 1B, 5A, 5B, 11A, 11B, and 11C, and column 1 line 20 to column 4 line 24.	1, 8, 15, and 17
A	US, A, 4,558,281 (Codd et al.) 10 December 1985, the entire document.	1-20
A	US, A, 4,709,202 (Koenck et al.) 24 November 1987, the entire document.	1-20
A	US, A, 4,595,880 (Patil) 17 June 1986, the entire document.	1-20
A	US, A, 5,248,929 (Burke) 28 September 1993, the entire document.	1-20